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ABSTRACT

The Instructional Support System for Occupational Education (ISSOE), developed in New York during the past five years, consists of a student-outcome-oriented curriculum that is locally developed and implemented by teachers. The teachers who have been using the ISSOE materials have indicated some difficulty in implementing the system because of the great number of tests which they are called upon to administer to the students in their classes. In order to lighten this burden an attempt was made to identify generic competencies and skills which subsume many other prerequisite skills and knowledges and, if existent, determine how to identify them and test for them. A review of the literature in the area of hierarchical learning structures and their relationship to testing of student competencies in occupational education suggests some relevance of these theories and measurements to courses in vocational education. In particular, the work of Gagne and of Scandura point to the usefulness of some sort of hierarchical learning structure in various content structures. Gagne's research is appealing because it provides distinct procedures for identifying and validating a learning hierarchy in a subject area. On a practical level, however, this model is extremely difficult to implement because a teacher would be expected to assess each student on each skill of the hierarchy. On the other hand, Scandura's structural learning theory states that there are underlying competencies which subsume many of the prerequisite and superordinate skills, providing for a manageable criterion-referenced testing system. An ideal system would combine the two approaches. (KC)

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INSTRUCTIONAL SUPPORT SYSTEM-OCCUPATIONAL EDUCATION II

ISSOE

HIERARCHICAL STRUCTURES IN OCCUPATIONAL EDUCATION - A SELECTIVE REVIEW

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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Introduction

During the past five years, the New York State Education Department (SED) has been involved in the development of the Instructional Support System-Occupational Education (ISSOE). As a system, ISSOE consists of a student-outcome oriented curriculum that is locally developed and implemented by teachers.

The teachers in the field who have been using the ISSOE materials have indicated some difficulty in implementing the system because of the great number of tests and measures which they are called upon to administer to the students in their classes. The problem is compounded because the system is modular and individualized so that in many instances different students may be working at different skills and tasks requiring different measures. The basic problem, therefore, reduces to one of finding a method for selecting samples of measures which would be indicative of underlying skills and knowledges on the part of the students, rather than requiring testing for every major objective. Or stated interogatively, are there generic competencies and skills which subsume many other prerequisite skills and knowledges and how do we identify these generic skills and test for them?

A major first step in such a study is a review of the literature in the area of hierarchical learning structures and their relationship to testing of student competencies in occupational education. The purpose of the present paper is to review this literature and to examine the relevance of hierarchical and structural learning theory and criterion-referenced measurement to courses in vocational education.

Several learning theorists have developed the notion of hierarchical models of learning. These models have been utilized in the study and implementation of the sequencing of instructional content and in the development of criterion-referenced measures. Although, in past research, hierarchical models have been applied primarily to mathematics and science curricula, it is clear that they could also be effectively applied to curricula in vocational education.

The present paper first describes the hierarchical models of two learning theorists, Gagne and Scandura. The issues of transfer and of criterion-referenced testing are addressed as an intrinsic part of these models. Next, learning hierarchies and criterion-referenced testing as they specifically relate to vocational education are examined. Again, special attention is given to the issue of transfer. Finally, the identification and validation of learning hierarchies is discussed, first in general, then in respect to curricula in vocational education.

Gagne's Model of Hierarchical Learning

Gagne (1977) describes a learning hierarchy as "an 'on-the-average' efficient route to the attainment of an organized set of intellectual skills which represents 'understanding' of a topic." (p. 143). He has presented a hierarchy of intellectual skills which proceeds from specific to general (Gagne, 1977, 1970) and suggests that rules are not learned in isolation. Rather, what is learned is an organized set of intellectual skills in which some skills are prerequisites of others.

Thus, a learning hierarchy is defined as a psychological organization of intellectual skills that is often composed largely of rules. It is, according to Gagne (1970), the best way to describe the structure of any topic, course, or discipline. The hierarchy identifies a set of intellectual skills that are ordered in a manner indicating substantial amounts of positive transfer from those skills in a lower position to connected ones in a higher position.

In this model, the attainment of intellectual skills is a matter of combining prerequisite skills which have previously been learned. In fact, Gagne (1977) defines "prerequisites" as a capability of prior learning which is incorporated into new learning. In other words, that which was previously learned enters into the newly learned capability. Although Gagne (1977) claims that learning hierarchies are only relevant for intellectual skills, he does point out that incorporated prerequisites are evident in the learning of motor skills. In these cases, prerequisites can be thought of as "part-skills" which compose the total skills. The place of motor skills in hierarchical learning models will be discussed later in this paper.

Gagne suggests that teaching and learning should proceed based on his hierarchical structure such that the higher levels within the sequence are arrived at after mastery of the lower levels and should not be attempted until the students have shown mastery of the lower level skills. Typically, then, a learning analysis is conducted by asking this question about each skill. "What [skill] should the learner already know how to do and be able to recall, when faced with the task of learning the new rule; the absence of which would make it impossible for

him to learn the new rule?" (Gagne, 1968).

A significant by-product of constructing learning hierarchies for a specific content area is the possibility of positive transfer from one area to another. Whereas vertical transfer refers to the effects that learned capabilities at one level have on those at higher levels, lateral transfer is the type of generalizing that spreads over a broad set of situations at roughly the same level of complexity (Gagne, 1970). The extent of lateral transfer depends upon how broadly on individual can generalize what has been learned to other situations. Individual differences aside, lateral transfer will increase with a more broadly based learned capability. Similarly, practice in a wide variety of situations that are different from each other will increase the usefulness of a learned capability. Clearly, instruction which encourages the student to apply a learned capability in many new and varying situations will be the most beneficial in terms of lateral transfer.

In his more recent work, Gagne (1977) speaks of cognitive strategies of thinking. These strategies are the ways in which an individual exercises control over his/her own thought processes by using selected previously learned capabilities in order to solve novel problems. The relationship between cognitive strategies and lateral transfer is evident. Lateral transfer must occur in order for the cognitive strategy to be learned. Nevertheless, Gagne points out that researchers who study the learning of these strategies have difficulty actually demonstrating their transferability. In order to show that a cognitive strategy has been learned, one must show that it is applicable to varying domains of

problems. It is difficult to empirically demonstrate that transfer has occurred across domains.

Within each learning hierarchy, there is a concern with vertical transfer. The occurrence of this type of transfer becomes evident where a skill to be mastered is acquired more rapidly if it has been preceded by previous learning of prerequisite skills. Gagne's whole hierarchical model of learning is based on the assumption that learning of these prerequisite skills must precede vertical transfer. Since Gagne (1970) claims that there are various paths that may be followed in the learning of any advanced capability, any variety of capabilities previously learned by the individual may enhance vertical transfer. In other words, a higher order rule may have as its prerequisite any number of different subordinate rules. In turn, the more of these subordinate rules that are known by the learner, the greater the positive effect on the unknown subordinate rules when a new principle is being learned. Although there is not much empirical evidence to attest to it, it is possible that the speed with which an individual learns a higher order capability is a function of the number of subordinate rules he/she has mastered.

Gagne does not really address the issue of criterion-referenced testing. He does suggest that the learner should be assessed at each level of the hierarchy, and that each rule should be tested directly and unambiguously (Gagne, 1970). More important, he indicates that, in regard to the learning hierarchy, it is useful to stop testing at prior skills at the point which has been identified as incorporating

the capabilities that can be assumed to be present in the group of learners. In other words, the lowest "boxes" in a hierarchy represent the kinds of performances all students in the group already know how to do. Thus, according to Gagne's theoretical framework, mastery of the higher levels of the hierarchy indicates mastery of the lower levels. The implication for assessment, then, is that since success at a higher level predicts success at all lower levels, it is not always necessary to test at the lower levels.

Although Gagne's early studies (Gagne and Bassler, 1963; Gagne, 1962; Gagne, Mayor, Garstens and Paradise, 1962; Gagne and Paradise, 1961), for the most part, lend support to the concept that intellectual tasks are organized in a hierarchical manner, they are not totally conclusive (White, 1973). For instance, in one of these experiments (Gagne and Paradise, 1961) there were a small number of subjects who while successful at performing the terminal skill of the hierarchy were unable to perform at least one of the subordinate skills. The authors suggest that these exceptions to hierarchical learning could have been due to errors of measurement. It was later posited that factors such as temporal delay in testing or invalid hierarchical connections could have been responsible for the exceptions (White, 1973). Nevertheless, it became clear that more and better research was needed before Gagne's hierarchical learning theory could be unquestionably accepted. In their review of the literature, White and Gagne (1974) suggest that the more recent investigations into learning hierarchies have been divided into the following issues: the validity of learning hierarchies,

vertical transfer, the generalizability of hierarchies, the presence of hierarchies in numerous content areas, and lateral transfer.

Although hierarchy validation will be discussed in detail later in this paper some of these studies will be briefly discussed now. Kolb (1967-68), using a hierarchy of mathematical skills, found that many of the subjects who succeeded at tests high in the hierarchy failed at the lower prerequisite tests. White and Gagne (1974) claim that these findings were due to the fact that Kolb's test did not consist of skill items but of knowledge items. Some other studies have called into question the theory of a hierarchical learning structure for intellectual skills (Capie and Janes, 1971; Merrill, 1965). White (1973) has detailed the methodological weakness of these studies.

In general, most of the later investigations into the validity of learning hierarchies have been supportive of Gagne's work (Linke (1975, 1973; White 1974a; Resnick and Wang, 1969; Resnick, 1967). For example, Linke (1975) using validation procedures set forth by White (1973), found only three significant discrepancies from 26 hypothesized connections in a validation study of a hierarchy of graphic interpretation skills. Then, using cross validation procedures with another group, he found only one discrepancy out of 26 connections. According to White's procedure, these connections between pairs showing significant discrepancies should be removed from the hierarchy. In a more recent paper, Cotton, Gallagher and Marshall (1977) suggest that if a large proportion of connections (15% or more) have been dropped

from the hierarchy, the modified hierarchy should be re-validated using different subjects.

The issues of hierarchy validation and vertical transfer are intimately connected since vertical transfer must be evidenced for the hierarchy to be valid. There have been numerous studies which suggest upward vertical transfer in hierarchies (Caruso and Resnick, 1972; Resnick, Siegel and Kresh, 1971; Merrill, Barton and Wood, 1970; Uprichard, 1970). These studies posit that relevant subordinate skills mediate transfer to the higher skill. For instance, it was found that children taught an easier prerequisite task before a difficult task learned more quickly than those children who were taught the difficult task first (Resnick et al., 1971). In Kolb's (1967-68) study, statistical evidence was found for positive transfer in learning a science unit for which hierarchically arranged mathematics items were prerequisite.

In their review of the literature, Cotton, Gallagher and Marshall (1977) discuss the possibility of downward vertical transfer in learning hierarchies. This concept refers to the training of a higher-level skill facilitating the acquisition of a skill below it in a hierarchy. In the case of downward transfer, the implication is that the tasks in question do not actually form a hierarchy since the higher-order task is attained without learning the presumed prerequisite tasks. Resnick et al. (1971) found that while eight out of thirteen children learned a higher-order task without being taught the lower-order task, six of these eight subjects were subsequently able to perform the lower-order

task in the minimum number of trials possible. Thus, it is possible that, for these six subjects, the prerequisite task was learned during the training of the higher-order task.

In general, studies of vertical transfer show that transfer is greater if the learners proceed from mastery of prerequisite skills to mastery of higher-order skills than the reverse (Cotton et al., 1977). Thus, Gagne's hierarchical theory that the learning of an immediate prerequisite to a skill results in positive transfer to that skill is possible, though yet unconfirmed.

In order for a learning hierarchy to be of practical value, it is important to know if it has applications beyond the sample on which its validation is based. This issue is of particular interest since a goal of the authors' research is to investigate the feasibility of hierarchically sequenced vocational courses and/or curricula that may be utilized with many sub-populations. In a major investigation into the generalizability of hierarchies, Linke (1973) validated a hierarchy of graphical skills with children in different grades in three separate areas of Australia, as well as with ninth grade Papuan children whose cultural background was extremely atypical. White and Gagne (1974) suggest that hierarchies should be generalized not only cross-culturally, but across different modes of instruction as well. They point out that learning hierarchy research is usually done with programmed books. It is important to determine if hierarchies are also valid when instruction follows a more traditional teaching mode. Thus, not only are validation studies across cultures, across schools, and across grades needed, but research into hierarchies across teaching methods is also necessary.

Another area of research which is of particular interest to the present paper is the existence of hierarchies in many content areas. As was mentioned in the introduction, hierarchical models have generally been applied to curricula in mathematics and science (White, 1974; Linke, 1973; Kolb, 1967-68) and generally have not been applied to curricula in vocational education. The Piagetian task of conservation was taught to young children by using a hierarchical model of instruction (Lefrancois, 1968). Recently, however, a validation study has been undertaken with a learning hierarchy in a non-mathematical electrical science course (Beeson, 1977). This study will be discussed later.

Finally, lateral transfer has been studied minimally because it is peripheral to learning hierarchy research since it describes the effect that one intellectual skill has on another skill that is not hierarchically dependent on it. Wiegand (1969) found that lateral transfer was evident from one skill involving the relationship between quantities associated with an object on an inclined plane to another skill encompassing different relationships between other quantities associated with the object. Perhaps Gagne's (1977) more recent theoretical conceptualization of cognitive strategies will encourage more research dealing with lateral transfer.

In sum, Gagne has hierarchically arranged intellectual skills from simplest to most complex in a vertical sequence. He suggests that teaching and learning should proceed based on this hierarchical structure such that the higher levels within the sequence are arrived at after

mastery of the lower levels and should not be attempted until the students have shown mastery at the lower levels. Thus Gagne's model, although empirically sound, is difficult in practice since it does not provide for criterion-referenced testing procedures which can be easily implemented in the classroom. If each learner is to be assessed at each level of the hierarchy, the testing will overwhelm the classroom teacher. Scandura, on the other hand, has presented some data that show that it is the underlying competences that must be tested in order to see whether learning has occurred rather than a particular behavioral objective (hierarchical level).

Scandura's Structural Learning Theory

The structural learning theorist maintains that rules underlie all behavior (Scandura, 1970). More specifically, this viewpoint is based on the assumption that the attainment of a particular skill by the learner can be traced to the presence of higher order rules. Thus, unlke Gagne who theorizes a learning hierarchy which proceeds from specific to general, Scandura's work points to the usefulness of learning hierarchies which go from the general (higher-order rules or underlying competences) to the specific (behavioral objectives or particular skills). Based on this structural approach, Scandura (1977a) outlines a cognitively based performance test theory and demonstrates the practical applications of this theory to instruction.

Scandura (1977a) criticizes the behavioral approach, claiming that it leaves the "guts" out of learning in that specifying behavioral objectives does not dictate what the learner must learn or what the teacher

must teach. According to structural learning theory, it is the underlying competence which must be specified. Because competence and behavior are intimately linked, specifying behavior alone is not sufficient. The behavioral objective, which may be compared to a skill on Gagne's learning hierarchy, tells only what the learner is supposed to be able to do. The underlying competence, on the other hand, tells what the learner must know or learn in order to achieve the behavioral objective. In short, "knowledge", in the present framework, refers to an underlying rule construct which reflects a potential for behavior (Scandura, 1977b).

The structural approach to criterion-referenced testing utilizes the notion of rules of competence. These rules are introduced to account for the learner's performance on given behavioral objectives and provide a foundation from which human knowledge may be measured. Scandura (1977b) suggests a learning hierarchy of sorts, consisting of rules of competence and corresponding subrules. He points out that there are a finite number of behaviorally distinct paths leading toward the achievement of a goal. Since each path is associated with a unique subclass of a particular rule of competence, it is possible to determine, through a finite testing procedure, what each learner knows relative to the initial rule. It is sufficient to test each learner on one item selected randomly from each subclass. Success on that item implies success on any other item in that subclass. Thus, individual knowledge is represented in terms of subrules of the given rules of competence. As will be discussed later, data confirm the success in pre-

dicting performance of this testing procedure.

An underlying competence, by its very nature, may be difficult to describe in explicit terms. Scandura (1977c) points out that although these competences are usually specified in terms of rules, in a formal and detailed manner, they need not always be described in terms of discrete entities. Citing examples such as coordinating pressure on the gas pedal in an automobile with a stick shift and utilizing kinesthetic feedback in wrestling, he suggests that continuous quantities and operations may also serve as representations of underlying competences. This may be particularly useful in the area of vocational education where activities are often physical and continuous in nature. It is the structural learning theorist's flexible approach to representing competences that makes the theory applicable to a broad range of subject areas.

The level of representation of a competence has important implications for criterion-referenced testing. Structural learning theory provides a way of dealing with the relationship betweeen behavior and competence. Rules of competence, which serve as an explanation for performance on given behavioral objectives, serve as instruments in the measurement of human knowledge. As was mentioned previously, a finite testing procedure may be used to determine which parts of the rules in question have been mastered by the learners. Thus, the rules "serve as rulers of measurement, and provide a basis for the operational definition of human knowledge" (Scandura, 1977c, 542).

Each rule may be broken down into a series of easily performable steps called "atomic units." These atomic units vary with the sophistication of the population of rules in question. Each rule consists of a behaviorally distinct finite number of paths and each path is made up of atomic units. Each path acts as an atomic unit in and of itself, since success on any path of a rule is dependent on the success of all of its atomic units. Collectively, the paths of any given rule "--define a set of distinct, exhaustive, and homogeneous equivalence classes of problems such that each problem in any given class can be solved via exactly one of the paths" (Scandura, 1977c, p. 542). Thus, since each path represents a unique subclass of a rule, it is possible to use a finite testing procedure in order to discover exactly which parts of the initial rule have been learned by the student. This is accomplished by testing the student on one item randomly selected from each path or subclass of the rule. Again, it is the assumption of the structural learning theorist that success on one item implies success on any other item of the same equivalence class. In sum, a student's knowledge or potential for behavior is represented in terms of rules and subrules of competence. A student's knowledge may be represented by one or more subrules (or paths of a rule) or by the entire rule (consisting of all of the subrules or paths). Thus, the structural approach makes it possible not only to discover which skills a student can and cannot perform, but to discern what he/she does and does not know relative to the rule in question. Mere performance on a skill does not always imply comprehensive knowledge of the underlying rule of competence.

Like Gagne, Scandura (1977c) addresses the issue of hierarchical transfer. He suggests that the student who is able to perform a task high on the hierarchy while skipping prerequisite skills does so because he/she has previously learned the higher-order rule that enables him/her to perform the task without instruction. Thus, Scandura's concept of higher-order rules corresponds to Gagne's concept of instruction. Both higher-order rules and instruction effect transfer from a lower to a higher-level of a learning hierarchy. It is Scandura's contention that knowledge of an underlying rule of competence, and not specific instruction on prerequisite skills, results in performing tasks high on the hierarchy. He argues that success on prerequisite tasks does not always imply success on superordinate tasks because a higher-order rule is often needed to make the transition from lower-level to higher-level skills. Consistent with this view, effective teaching is not simply a matter of presenting prerequisites according to a predetermined hierarchy. In order to succeed on the higher-order task, the student must know the higher-order rule that will permit him/her to utilize the learned prerequisites.

Empirical research into structural learning theory can be divided into two general categories: research dealing with the theoretical assumptions underlying the theory and research dealing with the theory's instructional applications and extensions. Although these studies are not necessarily exclusive, it is useful to make the distinction for the purpose of discussion. Since the former category underlies the latter, it will be discussed first.

Most of the structural learning research in the theoretical realm is concerned with the role of higher-order rules in behavior and problem-solving. In an early monograph, Scandura (1968) emphasized the importance of rules to structural learning theory by introducing a set-function language formulated in terms of mathematical sets and functions that takes as the basic unit of behavior the rule or principle. This language, is, in turn, compared to Gagne's S-R language that states that many higher forms of learning are based on simpler forms such as associations. It is not within the scope of this paper to describe this language, since the present authors are more interested in describing empirical studies that justify the application of structural learning theory to educational settings. It is mentioned only to stress, again, the importance of rules in Scandura's work. In a later paper (Scandura, 1970), it is argued that rules cannot be explained simply as networks of associations. They can, however, be formulated in terms of some associations on other associations. This formulation is used as a basis for showing how rules are involved in decoding and encoding, symbol and icon reference, and higher-order relationships.

The assumption that the attainment of a behavioral objective by the learner can be traced to the presence of higher-order rules was supported when Scandura (1974) studied why some problem solvers succeed on problems for which they have all the necessary skills, whereas others possessing these same prerequisite skills do not succeed. It was theorized that higher-order rules are used to combine component parts of a problem solution into a coherent whole adequate for solving the problems. Two of the experiments in this study provide support for the

hypothesis that in problem solving rules interact according to a fixed innate mechanism. This mechanism works such that when the effects of memory are controlled and the subjects's goals are known to the experimenter, the availability of appropriate higher and lower-order rules, not merely previously learned prerequisite skills, are a necessary and sufficient condition for problem solving. A higher-order rule is defined in the context of that rule's role in that particular instance of problem solving, and not in the nature of the rule, itself. The other two experiments demonstrate how these higher-order rules may be determined through testing and then used as a basis for explanation and prediction in problem solving. In these experiments, the overall percent of correct predictions were 85% and 92%.

In a study concerning the assessment of behavior potential (Scandura and Durnin, 1971), subjects were trained on individual atomic rules relevant to simple problem domains. Subsequent to this training, subjects were given a chance to learn to solve more complex and novel problems through manipulating, modifying, and combining these atomic rules in various ways. Then sets of test items were constructed. To examine the knowledge learned and the reliability of the assessment, subjects were tested on two items of each equivalence class. Given performance on systematically selected sets of items, performance on any other items in the same equivalence classes for a wide variety of tasks and populations was predicted with 96% accuracy. Furthermore, test-retest reliability was high. Thus, this study supports the hypothesis that success on one item of a given equivalence class indicates success on any other item in that class and that it often indicates success in certain other

equivalence classes (depending upon how learned atomic rules have been manipulated). This finding is relevant when subrules or paths have been hierarchically ordered such that certain subrules include others, since the former contain all of the atomic rules of the latter, plus some additional ones. Scandura and Durnin (1971) found that in 90 of 117 cases subjects who were successful on all subordinate tasks were also successful on the corresponding superordinate tasks - a finding similar to Gagne's hierarchical ordering. The notable difference between the structural approach and Gagne's methods is that the former allows for varying ways of solving a given class of tasks while the latter assumes that there is only one way.

In a study which seems to bridge the gap between research dealing with structural learning theory and that dealing with practical issues, Scandura's procedure for assessing behavior potential was compared to two other methods (Durnin and Scandura, 1973). Rules for solving subtraction problems were constructed in order to represent the different ways in which the subjects might attack the problems. The domain of subtraction problems were divided into equivalence classes based on these rules. In comparing the structural approach to the two other techniques, it was found that the test based on the structural method was better able to predict student behavior than were the other two tests. On the former test, students who correctly answered one item stemming from a specific underlying competence would succeed 84% of the time on the other items based on that same competence. In fact, when compared with other approaches, the structural approach had significantly better prediction regarding

failures. Furthermore, the structural learning assessment was found to be considerably more efficient in that, in spite of its superior overall predictability, it had 57% fewer items than each of the other two measures. Also, higher phi coefficients were evidenced with the structural learning measure. A major practical advantage of the structural approach is that fewer test items are needed to successfully assess mastery of an underlying competence and that any one of a number of equivalent test items will serve equally well.

As with Gagne's work, a serious shortcoming of the research to date of the practical applications of structural learning theory is that it deals predominantly with mathematics (see subsequent discussion) and occasionally with reading (Lowerre and Scandura, 1973).

In an early study which is of particular interest because it inadvertently points to the similarities between the work of Scandura and that of Gagne, Scandura (1969) set out to identify factors affecting the learning of hierarchically arranged expository material. This is not so much an experiment in structural learning as it is one in hierarchical ordering,in general. The findings are not unlike those mentioned previously in the section dealing with Gagne's work. Using a criterion-referenced test, it was found that practice in prerequisite tasks significantly improved the learning of superordinate skills, particularly when the prerequisite terminology is employed in the teaching of the superordinate skill. Results also showed that prior knowledge affects future learning only when this knowledge is prerequisite to the new material, and that learning can be maximized when prerequisite

tasks are presented prior to the higher level task. Finally, it was found that later learning cannot be insured by mere exposure to prerequisites. That is, the inadequate learning of prerequisite skills can not be compensated for later learning.

In the first study to demonstrate the practicality of representing curriculum content in terms of rules and higher-order rules, Ehrenpreis and Scandura (1974) used a structural or algorithmic approach in constructing a mathematics curriculum. The importance of this study lies in the fact that not only is it a field test in structural curriculum construction, but it provides educators with a guideline to constructing their own curricula in a structural manner. In this study, a structural analysis was successfully undertaken in order to identify the content in a mathematics textbook in terms of rules. The introduction of just five higher-order rules enabled the experimenters to reduce a total of 303 initial solution rules by 40%. Thus, two rule-based curricula existed: one original curriculum consisting of all 303 lower-order rules and one revised curriculum consisting of 169 of these lower-order rules plus five higher-order rules. The two curricula were experimentally compared. It was found that subjects working with the revised curriculum where rules had been eliminated did as well as those subjects who worked with the original curriculum and learned each rule directly. Furthermore, subjects exposed to the revised curriculum performed significantly better on new tasks beyond the scope of either curriculum than did the subjects taught with original curriculum. In sum, the subjects using a

structurally based curriculum were taught less but learned more.

This study showed that a network of higher and lower-order rules provide a viable basis for instruction. The procedures that were used in revising the math curriculum were as follows: A textbook was selected and all of the tasks implicit in the text were identified and stated as behavioral objectives. Rules were written for solving each of the tasks and parallels among these rules were identified. These parallels were based on a common structure and provide a foundation for developing higher-order rules. Finally, the original rules that were derivable by application of the higher-order rules to other original rules in the "characterizing set" were eliminated. These procedures are based on the assumption that each behavioral objective belongs to a set of tasks that can be performed or solved by applying a rule. Another assumption is that a curriculum can be represented in terms of finite sets of rules in which higher-order rules act upon other rules. Thus, in structurally-based curriculum construction a finite set of rules is identified and economically accounts for the desired behaviors. This procedure has as its basic unit behavioral objectives which are characterized in terms of rules and higher-order rules. The methods undertaken in this study provide a systematic way of dealing with interrelationships among the behavioral objectives that automatically introduce transfer into the curriculum. Strong transfer effects were evident with those subjects who had learned the higher-order rules.

Scandura, Wulfeck, Durnin and Ehrenpreis (1974) did a study of higher-order rules for solving geometry construction problems to determine if instruction in missing higher-order rules or subrules effects

transfer to new geometry construction problems and facilitates or obstructs the learning or use of subsequent rules. It was found that higher-order rules were compatible with human knowledge in that the paths of these rules acted in an atomic fashion. Since the paths of any rule divide the associated sets of tasks into subrules, a behavioral test of atomicity consists of determining whether learners' performance reflects the division imposed by the paths. Thus, a subrule or path acts in an atomic fashion if learners consistently succeed or fail on all tasks encompassed in the equivalence class of that path. This study also showed that higher-order rules do facilitate problem solving. Instruction helps and its effects are cumulative. That is to say, instruction in higher-order rules facilitates the learning of subsequent ones.

Although this research confirms the effectiveness of a structural approach, it is myopic in the sense that it deals with how learners perform in a specific problem-solving situation given the entry level knowledge of these rules. Studies are needed which investigate the structural approach to problem-solving over time (Scandura, et al., 1974).

Using the geometry construction tasks from this study, Wulfeck and Scandura (1977) applied structural learning theory to ongoing instruction to address the issues of knowledge growth over time and how to maximize educational value given instructional costs. They also described the first step toward computer implementation of the theory. A structural analysis was reapplied to the already analyzed domain of geometry construction problems and the underlying competence

was reduced to simple rules. These rules together with a universal goal switching control mechanism were implemented using the SNOBOL language that took sets of geometry construction problems as input and arranged them in a learnable order consistent with structural learning theory. A goal switching control mechanism is defined as "a possibly innate, possibly learned control mechanism that is assumed in the structural learning theory to be universally available to all human information processors, and to determine how all rules of knowledge interact (rules are unstratified with respect to goal switching control)" (Scandura, 1977, p. 147). Finally, this theoretical computer-derived sequence of problems was experimentally compared to random and learner-derived sequences. The structurally-based sequence was shown to result in better learning as well as effecting a close relationship between problem complexity and solution time.

In sum, structural learning research has tended to confirm both its theoretical and practical value. Its practical application is based on the fact that, with few exceptions, it is impossible to teach students directly everything that they need to know. Through the use of higher-order rules and subrules, it is possible, using indirect but comprehensive methods, to systematically and hierarchically teach a content area. Additionally, the structural learning approach lends itself to a manageable criterion-referenced testing system. Its applicability to all content areas, especially vocational education, needs to be further explicated.

Learning Hierarchies and Criterion-Referenced Testing in Vocational Education

The literature dealing with learning hierarchies and criterion-referenced testing in vocational education is minimal and for this reason, this section will focus on several issues which are intrinsically related to learning hierarchies in vocational education. First, Gagne's view of the learning of motor skills is presented. Second, the place of lateral transfer in areas of vocational education is described. Third, the issue of using product versus process as a basis for student evaluation is addressed. Fourth, the identification of tasks to be included in a hierarchically arranged vocational education curriculum is discussed. This fourth issue also serves as an introduction to the following section, the identification and validation of learning hierarchies.

By its very nature, vocational education is more frequently concerned with psychomotor skills than are the general and/or academic programs. In his earlier work, Gagne (1970) points out that learning hierarchies are only relevant for intellectual skills. In his later work (Gagne, 1977), however, he deals with motor skills as parts of intellectually-based hierarchies. He describes vocational type motor tasks as fine (since they require precision) rather than gross skills and also characterizes motor learning as a special case of discrimination learning. This is based on the assumption that since the individual already knows <u>how</u> to move his/her muscles, all he/she must learn is <u>when</u> to move them.

Gagne (1977) states that individual motor skills occur within larger units of activity called procedures. A procedure is defined

as an intellectual skill, often a rule, which determines sequence and with which certain subordinate rules are associated. Most vocational education activities consist of procedures that are composed of subordinate rules, that, in turn, consist of separately identifiable motor skills. Thus, according to Gagne, a hierarchy involving motor learning progresses from specific motor skills to the general procedure or intellectual skill on which it is based.

Although Scandura's work does not deal with a structural analysis of motor skills, it is reasonable to suppose that he would probably look upon Gagne's concept of a "procedure" as an underlying competence. That is to say, he might ask what underlying competence the learner must possess in order to perform the motor skills in question.

Gagne (1977) proceeds to divide motor skills into part-skills. He suggests that while these part-skills or separate motor skills may be practiced separately, they should ultimately be practiced as an integrated part of the whole skilled procedure. In vocational education, an example of a part-skill might be holding a hammer while an example of a motor skill might be hanging a picture on a wall. It is important to know if a part-skill that has been learned in the context of one motor skill can be utilized successfully in the service of a different motor skill. Can the student who holds a hammer correctly while hanging a picture also hold it correctly while building a cabinet? This question is an instance that raises the issue of lateral transfer.

A significant by-product of constructing learning hierarchies for one content area is the possibility of positive transfer from one area to another. Whereas within each learning hierarchy one is concerned with

vertical transfer, lateral transfer is the type of generalizing that spreads over a broad set of situations at roughly the same level of complexity (Gagne, 1970). Ausubel and Robinson (1968) suggest that lateral transfer can be enhanced by using course materials as a vehicle for transmitting transferable knowledge or developing transferable skills. Furthermore, they propose that lateral transfer can be facilitated by teaching learners general principles rather than specific solutions, knowledge, or skills. In a sense, this is similar to Scandura's claim that it is important for the learner to master the underlying competence rather than the particular behavioral objective.

A recent review of the literature was aimed at identifying types of personal and job characteristics that previous research had designated as common and potentially transferable from one work situation to another (Sjorgen, 1977). Sjorgen (1977) argues that all skills are transferable in the sense that when a skill is learned it is available for use in a variety of situations. Of the research reviewed, the Dictionary of Occupational Titles (U.S. Department of Labor, 1965) was the most comprehensive attempt to classify occupations according to common elements. Occupational skills were divided into three categories: data-oriented, people-oriented, and things-oriented. The third category includes skills most related to the types of psychomotor tasks often found in vocational education curricula. Nevertheless, it was found that the most common transferable skills were those involved in handling data.

In a more detailed endeavor reviewed by Sjorgen, the Generic Skills Project (Kawula and Smith, 1975) set out to identify the skills that are generic to a large number of occupations. These skills fell into five general categories: mathematics, communication, interpersonal,

reasoning, and manipulative. Skill clusters were then arranged hierarchically, according to the number of occupations that were represented in each skill. Behavioral objectives were written for each skill area and skill transferability was discussed for each area. For instance, in the area of mathematics, skills equivalent to a first year algebra course are transferable across many occupational situations. In the manipulative skills area, the domain most closely associated with vocational education, it was found that sensory acuity, manual dexterity, and coordination are transferable across a wide range of occupations.

Ergometrics (Cunningham, 1971) aimed at describing occupations in terms of their work elements and their requisite attributes. It was found that ability in the psychomotor and sensory areas seems to be somewhat more general across work elements than those in the cognitive areas.

In sum, Sjorgen's review supports the assumption that many skills are transferable across occupations. This transferability of skills enables one to set up learning hierarchies for each occupation or for each unit of study within an occupation and to examine the level of skill required for positive transfer. For example, someone who can type is an eligible candidate for a variety of occupations. Nevertheless, there is a difference between typing a business letter and typing an order requisition. At what level of distinction would typing skills not be transferable? One could answer this question by constructing intra- or inter-occupational learning hierarchies and studying the levels of positive transferability. Such a technique provides an effective and efficient system for both teaching and performance testing.

Criteria for assessment of student performance is of particular importance to vocational educators. Is it more important to assess the student process or the student product? Is it possible to look at the product and make assumptions about the process, or is it necessary to actually observe the process? Consider the following situation. Suppose a student in a carpentry program learns by means of a hierarchically arranged curriculum, to build a discrete unit of some sort, e.g., a wall, floor, room, house, etc. Should this student's behaviors or product be assessed at each level of the hierarchy placing the emphasis on process variables or at different product completion stages comparable to real work situations? If the student builds the unit and it has not collapsed within the year, should the student be given a passing grade for the course? If, however, student behavior or product is assessed at every level of the hierarchy and these assessments are later compared to the final product variable (in this example, the durability of the unit), the final product would serve as an external criterion which, in a sense, validates the hierarchy. Such an approach includes both product and process variables. Geis (1978) makes the distinction between behavioral objectives that are performance statements (process-oriented) and those which are consequence statements (product-oriented) and claims that this latter type of objective has generally been overlooked. It is Geis's opinion, and ours, too, that the use and measurement of product-oriented objectives, when appropriate, can do much to enrich the curriculum.

Harmon (1969) offered as an example of a product objective the statement

that "the student will be successful in meeting the criterion if the staffing committee at the dormitory agrees that his shoes have looked in good shape for one month." If the objective is to produce shined shoes (which meet the approval of the staffing committee), then clearly, a product statement is in order. The student should be free to choose one of several ways to shine his shoes providing that the end product is adequate. If, on the other hand, the teacher is more interested in measuring a particular sequence of shoe-shining behaviors, then a performance objective is indicated. Performance objectives however, frequently limit the students to the prespecified method of shoe-shining rather than any of the other possible acceptable methods.

However, when measuring product or consequence objectives, one is not forced to exclude <u>all</u> explicit constraints on the behaviors which result in the product. For instance, a student in carpentry who is asked to build a house may be told that only certain types of materials or tools may be used or that certain activities will not be permitted. Thus, within <u>reasonable</u> limitations, a product objective may be attained via various paths.

In sum, the question of whether criterion-referenced tests measure process or product should be a function of what is more important in a given instance. The measurement of a product often implies that any one of a number of processes have occurred. This may be either an advantage or a disadvantage, depending on the scope of the curriculum. An example, of criterion-referenced testing which measures both product and process is evident when process is assessed at each level of a learning hierarchy and product serves as an external criterion.

Whether applying Gagne's or Scandura's methods, the identification of tasks to be included in a vocational education curriculum must be accomplished prior to the identification of learning hierarchies or underlying competences within a given content area. This procedure is rather straight forward, as evidenced by the U.S. Army's (1978) attempt to identify tasks to be included in their occupational training curricula. Initially, consultants in the areas of curriculum design and the given content area identify the tasks they believe should be included in the curriculum. Typically, this is done by reviewing the literature and by utilizing the expert knowledge of the consultants. Once the task lists are compiled, representative samples of individuals working in the field are surveyed. In this manner it is possible to estimate the number of people who are actually performing and the amount of time spent on a given task. The result of the Army's identification procedures produced information such as the average percent of time spent on a particular task by all members of a given occupation and by only certain members (e.g., supervisor, apprentice) within that occupation. Based on these or other data, it is possible to determine which tasks should be included or excluded from the curriculum.

In a similar project, the Vocational-Technical Education Consortium of States (V-TECS) (Lee, Hirst, Hinson, Koscheski and Netrick, 1977) produced a catalog of tasks, performance objectives, and criterion-referenced measures for specific vocational occupations. They have defined task as "a unit of work activity or operation that constitutes a logical and necessary step in the performance of a duty." p. 3). In the vocational content area of automotive mechanics, for instance, a state-of-the-art study of the content domain was conducted. The result of this study was a preliminary listing

of automotive mechanics tasks and a collection of literature for project reference. Next, a representative group of four expert auto mechanics were engaged to supplement the task list and a task inventory was administered to a sample of auto mechanics in the field. Finally, a job inventory booklet that included sections dealing with background, tools and equipment used, and tasks performed was administered to a group of randomly selected automotive mechanics, supervisors, and service mechanics. Analyses of data yielded an index of time spent performing tasks, a standard deviation of time spent, a duty/task list, the percentage of workers performing tasks, equipment used by workers, and equipment used by percentage rating. Based on these findings, performance objectives and criterion-referenced measures were written. The procedures followed were: 1) Tasks performed by 30% or more of the workers were usually accepted for further development. 2) Depending on the time spent index, some tasks performed by fewer than 30% of the workers were discarded. 3) Tasks which were below the 30% mark were analyzed for criticality before being excluded. 4) Tasks were analyzed in terms of difficulty and some tasks above the 30% mark were discarded because of minimum skill requirements.

Ammerman (1977) suggested three categories for the compilation of task lists. The first and most typical is within a single job classification, such as auto mechanics or legal secretaries. The second is within a particular occupational area, such as secretarial science. This category may incorporate tasks of several job classifications within one list. A third category is to list tasks within a single work function cutting across several jobs in an occupational area, such as purchasing, sales, supervisory, and merchandise displaying tasks in a retail trade store occupational area.

These two latter categories have important implications for the formation of learning hierarchies and lateral transfer since they allow for the commonality of tasks. The identification of tasks to be included in a curriculum is the preliminary research which is needed before learning hierarchies can be constructed and criterion-referenced tests can be written.

Identification and Validation of Learning Hierarchies

It would be impossible to have a meaningful discussion concerning learning hierarchies and criterion-referenced measures in vocational education without mentioning the procedures used in the identification and validation of learning hierarchies. For the most part, the recent research dealing with these issues has been based on Gagne's model of hierarchical learning. This section discusses some of the major work in this area and describes an example of a "quasi-" vocational education curriculum that is based on this work.

Gagne was the first researcher to develop a validation model for learning hierarchies (Gagne, 1962; Gagne and Paradise, 1961; Gagne et al., 1962). The model consists of seven steps: 1) A task is stated in behavioral terms. 2) By asking the question, "What would the learner have to be able to do in order to learn this new task, given only instruction?", elements of knowledge which are subordinate to the initial task are derived. 3) A learning program is written in order to teach the elements of the derived hierarchy. 4) A sample of subjects works through the learning program. 5) Subjects are tested on their attainment of the elements of the hierarchy. 6) For each hierarchical connection, the results

of these tests are summarized in such a manner that subjects fall into one of four categories: those who learned both elements, those who learned neither, those who learned the superordinate element only (contradicting the hierarchy), and those who learned the subordinate element only. 7) The hierarchical connections that have large numbers (significant beyond chance) of subjects who have learned only the superordinate element are removed from the hierarchy.

Much of the early research into the identification and validation of learning hierarchies was conducted by White who subsequently developed his own model (White, 1973, 1974a, 1974b). Characteristics of White's (1974a) model which are absent from Gagne's model include a check of the face validity of the hierarchy by expert teachers, the investigation of possible division of elements, the embedding of questions for elements within the learning program, and the use of a statistical test of hierarchical dependence which takes errors of measurement into account.

White's (1974a) model may be stated in nine steps: 1) The superordinate element of the hierarchy is defined behaviorally. 2) Subordinate hierarchical elements are derived by asking Gagne's question from the superordinate element downward. Any reasonable connection should be included since it may always be discarded in the validation process. Verbalized knowledge elements should be excluded since they can be included in the instruction. 3) The usefulness of the hierarchy is examined by teachers and experts in the content area. 4) Possible divisions of hierarchical elements are constructed to add precision to the definitions. 5) These divisions are tested if they represent different skills by writing questions for each division and administering them to subjects. The divisions are considered

separate skills if subjects answer one division's questions correctly and the other's incorrectly. 6) A learning program is written that includes test questions for each element following immediately the teaching of that element. Two or more questions allow for a reliability check. 7) A minimum of 150 subjects work through and answer the questions in the program. 8) A test of hierarchical relationship developed by White and Clark (1973) is applied to determine which hierarchical connections should be discarded. The null hypothesis of this test is that the proportion of the population from which the sample was drawn who can learn the superordinate element, without the subordinate element, equals zero. The alternative hypothesis is that this proportion is greater than zero. Estimates of the probabilities of the observed results are provided given that the null hypothesis is true or given specific values of the proportion under the alternative hypothesis. 9) Discard all hierarchical connections for which the probability under the null hypothesis is less than .05.

White's model combines a content validation approach with an empirical and statistical approach. The hierarchy is content validated by bringing in outside consultants such as teachers and curriculum experts. An empirical validation takes place when students work through the program. Finally, the hierarchy is statistically validated. This model provides a built-in opportunity for criterion-referenced testing.

Recently, White's model was used in successfully constructing a learning hierarchy in electrical science (Beeson, 1977), a content area that is of interest to both science teachers and vocational educators. The superordinate element of this hierarchy concerned the determination of quantities in electric circuits. This study provides support for the distinction between intellectual skills and verbal information elements in learning hierarchies.

Within this hierarchy, the division of elements suggested in step four of White's model, was often the result of attempts to separate skill and verbal information parts of elements. All of these types of divisions were later validated. In accordance with the model, test questions were embedded in the learning program with two questions for each intellectual skill element or division and one question per verbal information element since the author felt that such a question would elicit all necessary information. For the most part, verbal information elements were found to be subordinate to intellectual skills.

Various statistical indexes have been developed to test the validity of learning hierarchies. Some of the earlier methods have been described in a review article and their shortcomings set forth (White, 1973). It was found that these early techniques generally overlooked errors of measurement, employed inadequate statistics, and made subjective judgements regarding mastery status. Other methods of statistically validating hierarchies have been proposed recently and are described below.

An ordering-theoretic approach was established to determine hierarchies among items (Airasian and Bart, 1975; Bart and Krus, 1973). This approach utilizes contingency tables or matrices to focus upon the percentage of subject responses which contradict the postulated existence of hierarchical connections between pairs of skills. A st[illegible]stical test then determines if the percentage of subjects who succeed on the superordinate skill while failing on the subordinate skill does not exceed an arbitrarily predetermined level of tolerance. This test is systematically applied to all possible combinations of skill pairs in the hierarchy, even if the skills are not

postulated as hierarchical. The result is the identification of a learning hierarchy. Like earlier methods, errors of measurement are not taken into consideration. Furthermore, there is no provision for determining statistical confidence in respect to each accepted hierarchical relationship (Griffiths and Cornish, 1978). The White and Clark (1973) test of inclusion is another method that focuses upon the comparison of pairs of skills and was described earlier as part of White's hierarchical validation model. In this approach, subjects answer two or three questions per skill. A skill by skill matrix is constructed with scores ranging from zero to two or three, according to the number of questions per skill. If a cell displays a score of zero for the subordinate skill and a maximum score for the superordinate skill, it is used to test the hierarchical relationship. This technique is based on testing the null hypothesis that there will be no entries in the cell in question other than those explained by errors of measurement. Marginal totals are used to compute the probability that the observed frequency does not violate the null hypothesis. Unlike the ordering-theoretic method, this test takes errors of measurement into consideration, as well as providing for a test of statistical significance. Linke (1975) revised the method so it allows for the same procedures to be used with one or two percent exceptions and exceptions due to errors of measurement. The result of this modification is that the hierarchy may not be empirically "perfect".

The White and Clark test is limited to equal numbers of questions per skill and to a maximum of three questions per skill. Because of this limitation, Griffiths and Cornish (1978) modified the White and Clark procedure to allow for unequal numbers of questions per skill and any number of questions per skill and they changed the significance test in accordance with the above modification.

In an approach that considers the hierarchy as a whole, rather than comparing pairs of skills, Dayton and Macready (1976) formulated a probabilistic model for hierarchy validation. Essentially, this model is based on Guttman's (1944) work, although the non-branching and linear pattern of the Guttman scale has been much extended and modified to fit hierarchies of any configuration. In a rather complicated set of procedures, Dayton and Macready (1976) applied scaling procedures to the validation of learning hierarchies. The obvious advantage of this approach is that it considers the hierarchy as a whole rather than constructing a composite hierarchy from the results of comparisons between pairs of skills. Unfortunately, this probabilistic model can only be implemented by a computer program which, at present, can only accommodate small hierarchies.

The identification and validation of learning hierarchies has all been based on Gagne's model. No similar research has been applied to structural learning theory. However, Scandura (1974) does discuss the possibility of systematically identifying the basic rules underlying a set of problems. The first phase is accomplished by selecting a broad and finite sample of problems from a set and identifying solution rules for each problem. These rules provide an adequate basis for solving the sample problems, as well as problems from the same equivalence class. In the second phase, parallels are identified among the previously indicated solution rules. Such parallels identify the presence of both higher and lower-order rules from which the solution rules can be constructed. These procedures may be repeated as many times as is necessary. Clearly, this method of identifying rules is not as statistically or empirically

satisfying as are the methods for identifying and validating learning hierarchies which were discussed in the preceding paragraphs. Nevertheless, Scandura does provide a much needed theoretical basis for future research into the identification and validation of lower and higher-order rules.

Conclusion

Both the work of Gagne and of Scandura point to the usefulness of some sort of hierarchical learning structure in various content areas. Although both have concentrated their efforts on intellectual skills in the areas of mathematics and science, a model of hierarchical learning could be of great use to vocational educators especially to those attempting to implement the ISSOE system. There is reason to believe that motor and knowledge skills, as well as intellectual tasks, could be effectively included in a hierarchy representing a content area of vocational education.

The research of Gagne and his followers is empirically appealing because it provides distinct procedures for identifying and validating a learning hierarchy in a given subject area. On a practical level, however, this model is extremely difficult to implement. In a mastery learning situation, an individual teacher would be expected to assess each student on each skill of the hierarchy. In vocational education, in general, and ISSOE in particular, with its many objectives, this procedure appears to be a herculean task for the instructor that may be theoretically unnecessary. The basic problem reduces to one of finding a method for selecting samples of measures which could be indicative of underlying skills and knowledges on the part of the students, rather than requiring testing for every task and sub-task. Scandura's structural learning theory states that there are underlying competences which sub-

sume many of the prerequisite and superordinate skills. His theory provides for a manageable criterion-referenced testing system which, generally speaking, groups tasks according to their underlying competence.

An ideal system for hierarchical learning would combine the empirical "know-how" of Gagne and his associates in identifying and validating hierarchies with Scandura's theoretical notion of underlying competences and his practical system of criterion-referenced testing. Research studies are needed that would investigate the theoretical and practical advantages of such a merged system.

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